Chapter 3

Reconstruction of the Spatial Composition and Microclimate of “Siheyuan” in Qing Dynasty, Beijing Through Cross Disciplinary Research: Towards clarification of the climate responsive mechanisms of vernacular architecture

JIANG Guangbo

1. Introduction

1.1 Research Purpose

It is well known that vernacular architecture has formed a complex climate adaptation mechanism in history. These mechanisms can create comfortable climate conditions, low energy consumption and a comfortable experience.

The main purpose of this study is to interpret the climate adaptation strategies and experience of improving comfort displayed by vernacular architecture, and to accumulate them as a method that can be transferred to today's architectural design.

1.2 Research object

The representative vernacular architecture in north China – Siheyuan(四 合 院) (Figure 1) has been chosen as the research object.

The figure 2 shows the layout of a typical Siheyuan. The four buildings of a Siheyuan are normally positioned along the north-south and east-west axis. The building, which is positioned

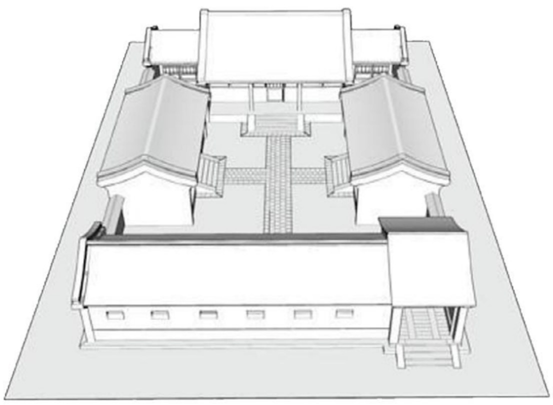


Figure1 A model of Siheyuan, JIA, J. (2009), p. 29.

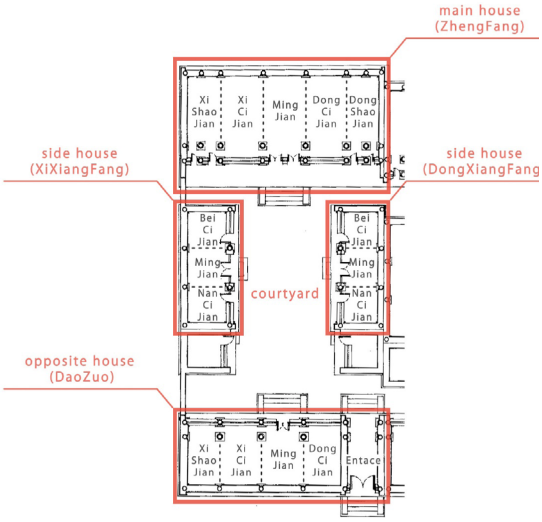


Figure2 The plan layout of Siheyuan (Mei Lanfang's former residence) Wang, S. R. (2002). Xuan Nan Hong Xue Disposition (宣南⊠雪⊠志 , Chinese edition). China: China Architecture and Architecture Press, pp.276.

to the north while facing south, is considered as the main house (“ZhengFang” 正房). The buildings, which are adjoined to the main house while facing east, and west are called side houses (“XiangFang” 厢房). The building that faces north is known as the opposite house (“DaoZuo” 倒座). There is a courtyard in the middle.

The layout of the simple courtyard represents traditional Chinese morality and Confucian ethics. In Beijing, the four buildings in the single courtyard receive different amounts of sunlight. The northern main building receives the most, thus serving as the living room and bedroom of the owner or head of the family. The eastern and western side buildings receive less and serve as the rooms for children or less important members of the family. The southern building receives the least sunlight, and usually functions as a reception room and the servants' dwelling, or where the family would gather to relax, eat or study.

Usually, each building is divided into an odd number of rooms. The middle room is called the "MingJian"(明 间), the two sides of the room are called the "CiJian"(次 间), and the rooms further away are called the "ShaoJian"(稍 间). As shown in the picture, the main house is divided into 5 rooms, from west to east: “XiShaoJian”(西稍 间), “XiCiJian”(西 次 间), “MingJian”(明 间), “DongCiJian”(东 次 间), “DongShaoJian”(东 稍 间). Usually “MingJian” is a living room, “CiJian” is a bedroom, “ShaoJian” is a room for other functions such as a teahouse, a study.

This layout dates back to the Xia Dynasty in 1600 BC and can be seen in the unearthed ruins of the Erlitou Palace of the Xia Dynasty. There is a building on the north side of the courtyard, surrounded by corridors on all sides. In the 1970s, an archaeological team excavated the site of a Yuan dynasty residential building called “Houyingfang”(后 英 房) in Beijing, which is considered to be the prototype of Siheyuan. A budding form emerged in the Xia Dynasty, and it was developed in the Yuan Dynasty. In the Qing dynasty, the Siheyuan form we see today was formed (Figure 3).

In addition, the central axis of Siheyuan is endowed with special significance. The east side corresponds to "Wen"(文) and the west side corresponds to "Wu"(武). Generally speaking, "Wen" on the east side is endowed with higher cultural value than "Wu" on the west side.

1.3 Previous Research

The study of Chinese architectural history has always been centered on monumental buildings. After Liu Dunzhen published 『中国住宅概論』in 1956, he began to turn his attention to vernacular architecture. After the 1980s, the research on the vernacular architecture of Siheyuan became more prominet. Zhao Zhengzhi「元大都平面計画復原の研究」(1979) is a pioneer in the research of block division method, which is closely related to Siheyuan. For the existing courtyard, Wang Shiren conducted a field survey, and his results were included in『宣南鴻雪図志』(2002) and『東華図志』(2005). In 2009, Jia Jun published『北京四合院』.Taking Beijing as the center, he has studied the urban space composition of Siheyuan. In Japan, studies on siheyuan have increased since 2000, and the results have been published in a number of books. Including『北京の四合院　過去・現在・未来』(2008). This book contains the research results of Masaki Fujikawa and Yasushi Kamikita, who identified the Siheyuan as a component of the urban composition of Beijing and discussed the transformation of the Siheyuan as the urban space changes from various perspectives.

Although there are so many related research, three main problems can be identified in the study of Siheyuan in the history of Chinese architecture.

1. Most of the examples of Siheyuan cited in the

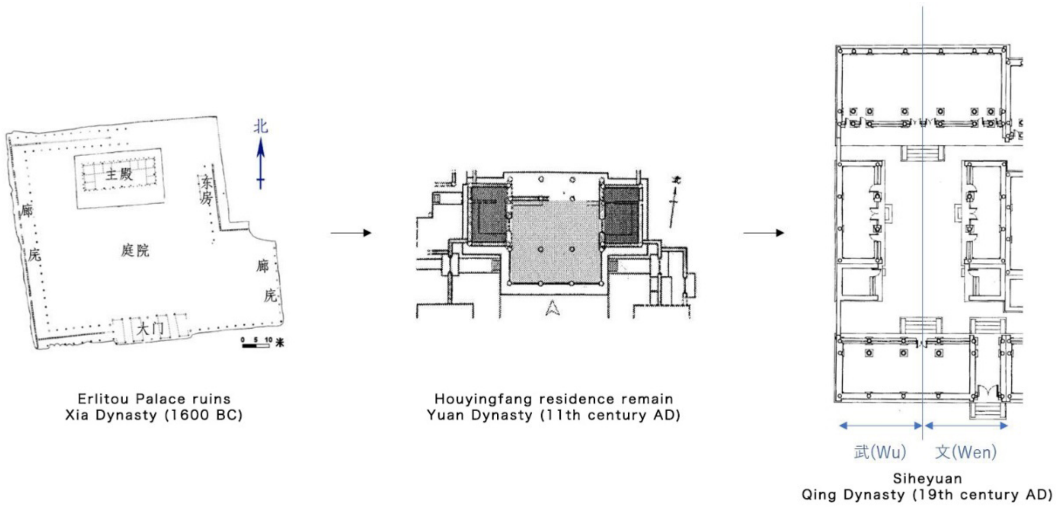


Figure3　Schematic diagram of the evolution process of Siheyuan

literature do not explain their construction period. As mentioned earlier, the layout of Siheyuan has a development process. Hence the Siheyuan of different dynasties are different from each other.

2. It is not clear according to what dimensional system Siheyuan was built.
3. The illustrations in many books are not based on real buildings, they are drawn based on theories.

In recent years, interest in passive design techniques of vernacular architecture has led to research on the thermal environment analysis of Siheyuan. Some studies have simulated the thermal environment of Siheyuan and analyzed its indoor climate characteristics. Climate simulation program was constructed to analyze and reconstruct the thermal environment of nonexistent buildings. However, the uncritical use of the research results of architectural history in the establishment of the Siheyuan model leads to the following two problems:

1. The model used is based on the data of an uncertain Siheyuan.
2. The lifestyle and heating system are based on the present, which is different from the situation of Siheyuan living in the past.

1.4 Research Methods

In order to solve the five problems mentioned above, this study has combined the three different majors of "architectural history", " Area studies" and " environmental engineering" (Figure 4).

From the perspective of Chinese architectural history, this paper analyzes maps and summarizes the dimensional proportion of Beijing blocks and Siheyuan space in Qing Dynasty by using previous research results, and constructs the space model of Siheyuan.

From the perspective of Chinese architectural history, this paper constructs the heating equipment model of Siheyuan in Qing Dynasty according to the previous records. From the perspective of area studies, people, who have experience in using this heating equipment, are interviewed through questionnaires to understand its usage mode and recover life scenes that reflect how they are used.

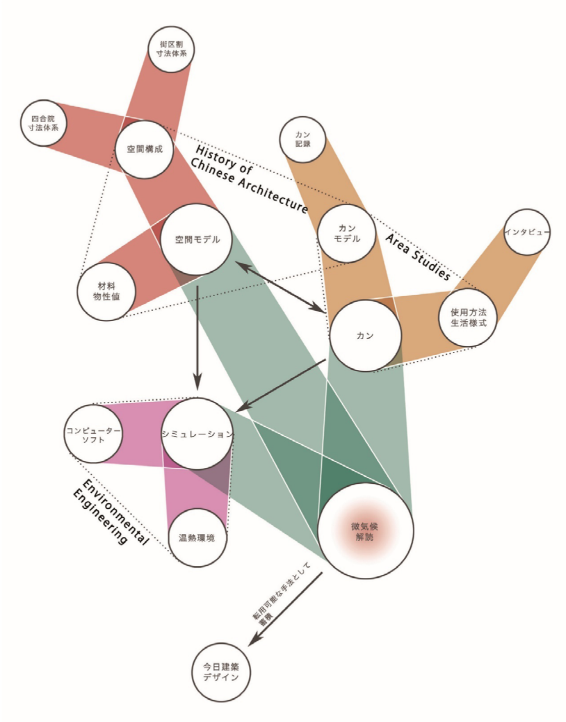


Figure4 Integration of three major research areas - architectural history, area studies, environmental engineering

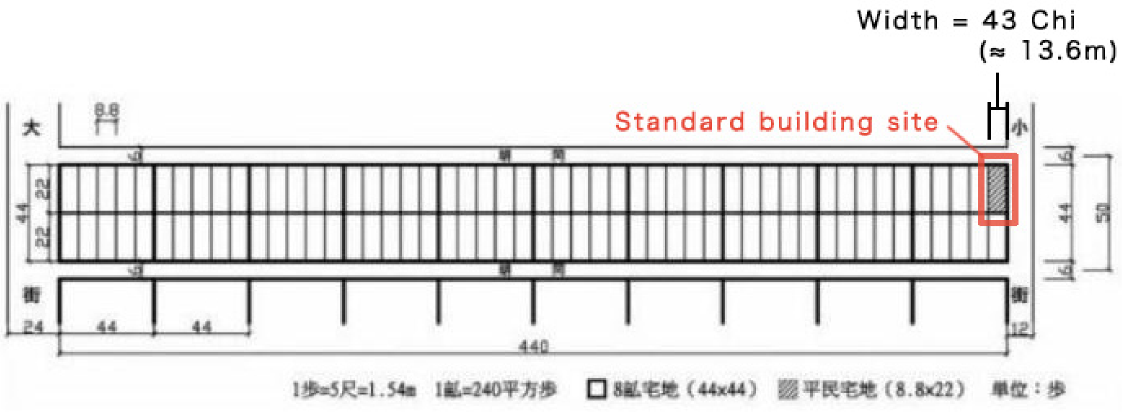
Finally, from the perspective of environmental engineering, a computer program was constructed and run to simulate the thermal environment of the constructed model, analyze and understand the experimental results and grasp the climate adaptation strategies.

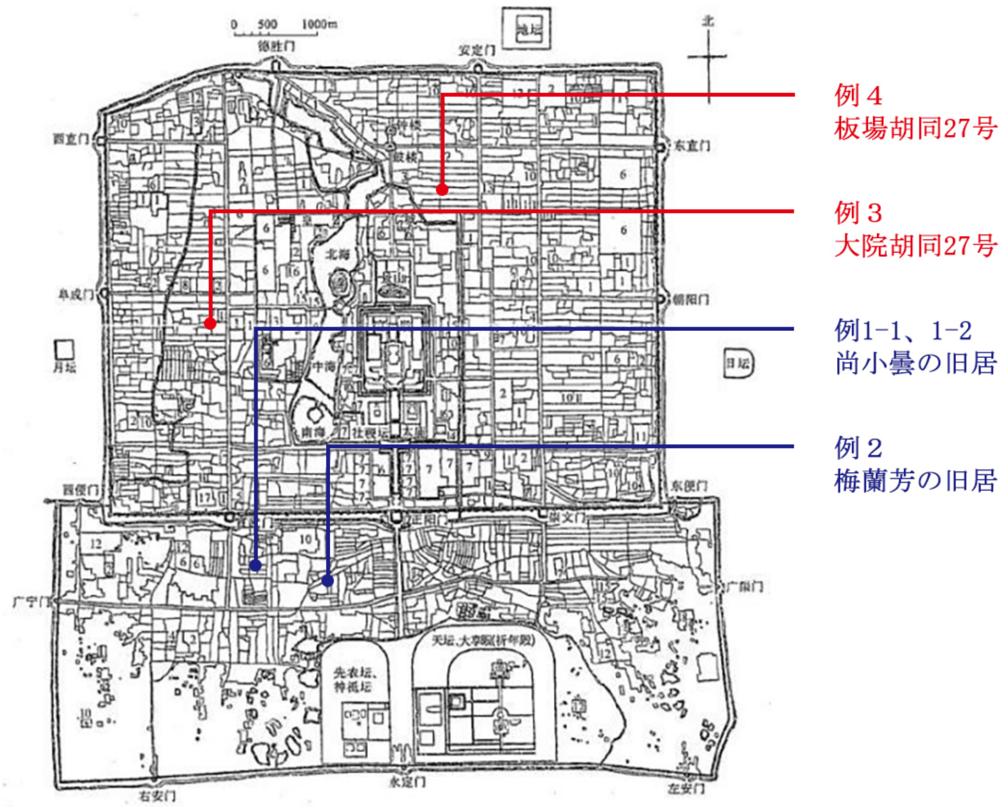
2. Dimensional System and Model Construction

In the first part of the research methodology,. based on the research of the architectural history, this research clarifies the dimensional system of Siheyuan, and how to build a model.

2.1 Dimensions of Building Site

According to Zhao's research, during the Yuan dynasty's urban planning (Figure 5), the width of





CASE NUMBER	ADDRESS	RESIDENTS	PLANE COMPOSITION TYPE
Case1-1	椿樹下二条 1 号(west)	尚少雲	縦向複合型の二進
Case1-2	椿樹下二条 1 号(east)	尚少雲	縦向複合型の三進
Csae2	鉄樹斜街 101 号	梅蘭芳	縦向複合型の二進
Case3	大院胡洞 25 号	鑲紅旗貴族	縦向複合型の二進
Case4	板場胡洞 27 号	鑲黄旗貴族	縦向複合型の二進 (三進があると推測される)

Top: Figure5 Yuan Dynasty Beijing block planning diagram

Middle: Figre6 Location of 4 cases (map of Beijing in Qing Dynasty)

Left: Table1 Summary of 4 cases

a standard building site was 43 Chi(尺) , which is about 13.545 meters. It can be considered that the basic composition of blocks of Beijing of Qing Dynasty followed that of Yuan Dynasty and remained basically unchanged. So, in this research the width of the building site has been set to the standard Siheyuan 43 Chi.

2.2 Determine the measurement object

Today, some Siheyuan built in the Qing Dynasty have been preserved. However, due to the impact of COVID-19, it was impossible for the main researchers to go to Beijing for mapping. The selected research solution was to make secondary measurements using measured drawings.

The first step was to screen eligible measured drawing cases. For this two criteria have been used. First is the width of the building site which should be closer to 43 Chi. Second is the construction period which should be in Qing Dynasty.

In this way, 5 eligible Siheyuan measured drawing cases were found (Table 1).

Figure 6 shows a map of Beijing in Qing Dynasty. 5 cases are located in the location shown in the picture. Of these, three are in the outer city of Beijing and two are in the inner city. The inner cities were inhabited by the Manchus, who were of the same clan as the ruler, and
some houses in the inner cities were more luxurious than those in the outer cities.

2.3 Measuring the size

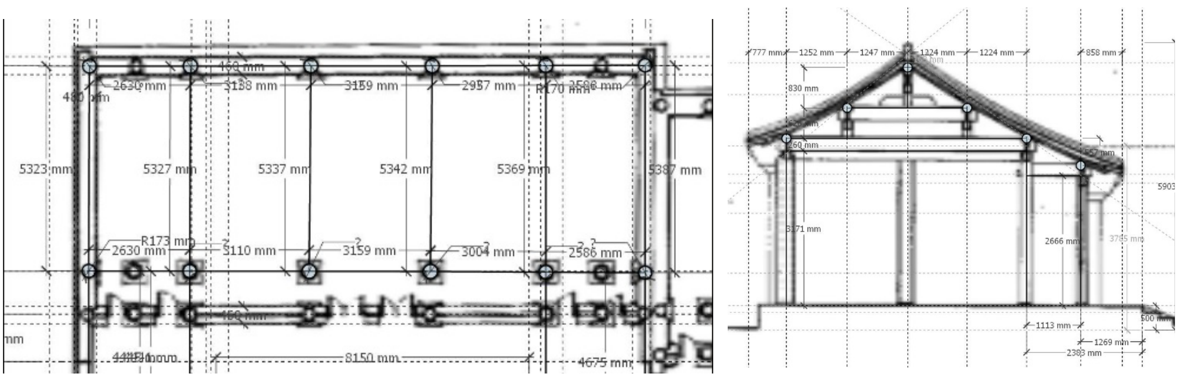
Every case was thoroughly measured. As shown in the figure 7, this is the main house of case 1-1. The width, height, column diameter, wall thickness, column height and roof slope of each room in the main house were measured. These data were recorded in a table to find out the size system of Siheyuan and verify whether the size system quoted in textbooks is suitable for civil Siheyuan.

2.4 Discovery of the Size System

In this paper, the main house has been taken as an example to show the specific content. Measurements were recorded for each part of 6 main houses in 4 cases (Figure 8), including plan data and elevation data. The plan data included: the width of each room, the depth of the main house, the width of the front porch, the diameter of the columns, and the thickness of each wall. The elevation data included: the height of the base, the height of the sill wall, the height of the columns, the dimensions of the various parts of the roof timber structure.

Dimensions were measured by a Chinese traditional unit of measurement, "Chi"(尺). The length of each Chi varies from dynasty to dynasty. There is no unified official conclusion on the specific conversion relationship at present. It can be seen in 『清代量度単位探究』 that if the ruler is converted into mm, there are three possibilities, that 1 Chi is 315mm, 320mm and 325mm. In order to determine the conversion relationship, the dimensions of the main house of example 1-1 measured in millimeters by 315, 320 and 325 were divided, and determined that the 315mm is the nearest integer to 1 Chi. The one that comes closest to the 1 Chi was 315mm and hence 315mm was considered as equal to 1 Chi.

With this table, the dimensional characteristics of each part can be summed up more easily. For example, the dimensional characteristics of the width of the MingJian in the main house can be easily determined. Six values that are approximate multiples of 0.5 were taken and they ranged from 9.5 Chi to 11 Chi. The largest width of a MingJian is 11 Chi, and there are three of them.



Figre7　Measurement photos of Case 1-1(The left picture is the plan of the main house and theright picture is the facade of the main house)

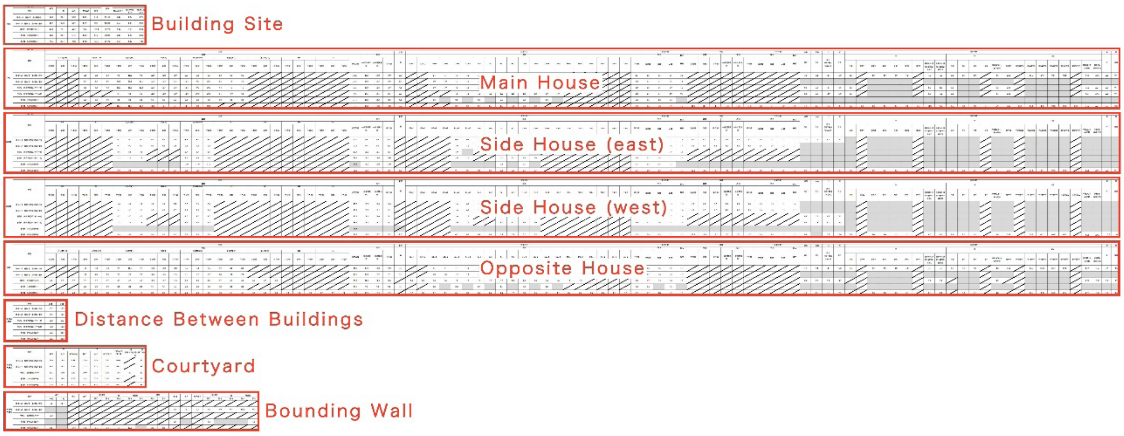


Table2　Reference table of measurement results

Figure8　The data of each part of the main house, and the data analysis chart of the Mingjian of the main house

Through this method, some size systems have been summed up. Systems include two aspects. First, it is the range. For example, a main house usually consists of five rooms. The rooms in the middle are between 9.5 and 11 Chi wide. The width of the rooms on either side is between 8 and 10 Chi. The second is the relationship of proportion. For example, the width of the room in the middle is wider than the width of the room on either side. The ratio of the width to the length of the building site is 2 to 3 or 1 to 2. The ratio of width to length of the courtyard is 2 to 3 or 1 to 2.

Through measurements, it was found that the rooms on the west side were more spacious. As mentioned above, the east and west sides were given the meaning of "Wen" and "Wu" respectively. Unlike the Han, the Manchus, who established the Qing Dynasty, attached more importance to the west side of the room than to the east, reflecting their cultural values.

2.5　Building 3D Models

After summarizing some basic rules of the size system, the 3D model of Siheyuan was built according to these systems. Since the width and length ratio of the building site are 2 to 3 and 1 to 2, the plan model of the Siheyuan was also established according to the two different proportions.

Firstly, when the width and length ratio of the building site is 2 to 3, the Siheyuan model plan was constructed by dividing into seven steps (Figure 9):

The first step was to calculate the size of the building site. Since the width of the building site was set at 43 Chi and the width to length ratio was 2 to 3, the length of the building site was calculated to be 64.5 Chi.

The second step was to determine the width of each room in the main house and the opposite house. The room in the middle of the main house is 9.5 Chi wide at most, and the other four rooms are 8 Chi wide. The widths of the rooms of the opposite house are not constant. In this model, the same layout as the main house was applied.

The third step was to determine the depth of the side houses and the width of the courtyard. There were two cases. The width of the courtyard is the maximum, and the depth of the side houses is the minimum. The width of the courtyard takes the minimum value, and the depth of the side houses take the maximum value.

The fourth Step was to calculate the length of the courtyard. The ratio of the width to length of the courtyard is also 1 to 2 and 2 to 3. Therefore, the length of the courtyard has four situations as shown in the figure.

The fifth step was to determine the depth of the main house and the opposite house.

The sixth step was to determine the width of each room of the side houses, as well as the distance between the main house, the side houses and the opposite house.

The seventh step was to remove the condition that does not meet the condition. Get the final Siheyuan plane model.

In a similar way, the layout of Siheyuan with a width to length ratio of 1 to 2 was deduced (Figure 10).

Then, on the basis of the plan model, the elevation model was generated. There were 8 steps to generate the elevation model (Figure 11):

The first step was to determine the height of the base.

The Second step was to determine the height of the column.

The Third step was to determine the height of "beam + 1/2 purlin".

The fourth step was to determine the roof slope according to the proportions of the lift.

The fifth step was to build interior partitions

The sixth step was to determine the size of the sill wall.

The seventh step was to determine the eave length.

The eighth Step was to determine the height of the bounding wall.

Finally, 4 3D models of Siheyuan were obtained (Table 3). Their differences are mainly reflected in the ratio of width to length of the building site, the number of courtyards, the ratio of width to length of the courtyard, and the number of rooms in the side houses.

3. Reconstruction of “Kang” and Life Pattern Using “Kang”

3.1 Introduction

Now, Beijing's Siheyuan has been restored and protected as a material cultural heritage. But unfortunately, due to the advent of new heating systems and lifestyle changes, the former heating equipment has not been retained. In the book『北支の住宅』, there is a record of "Kang"(炕), the heating equipment of the Siheyuan in Beijing in the Qing Dynasty. The function of the kang is similar to that of a bed, but because of its ability to generate heat, people spend time on the kang

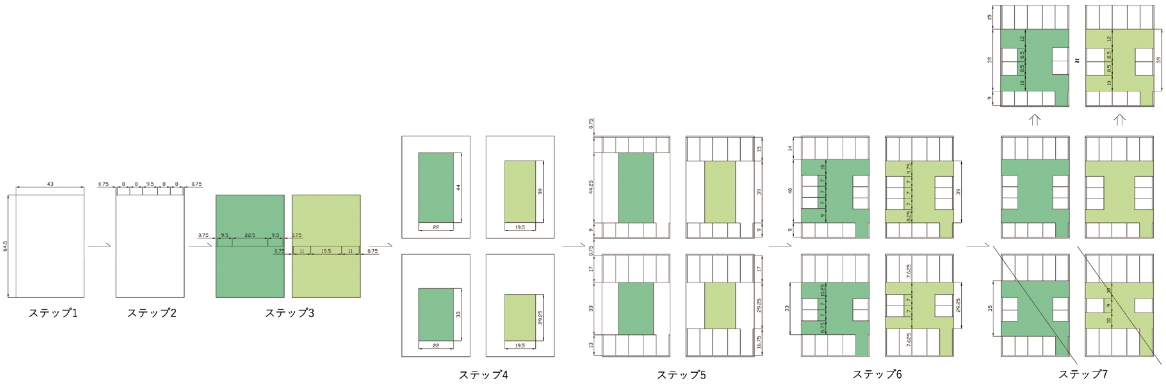


Figure9　The formation process of Siheyuan plane (when the width and length ratio of the building site is 2 to 3)

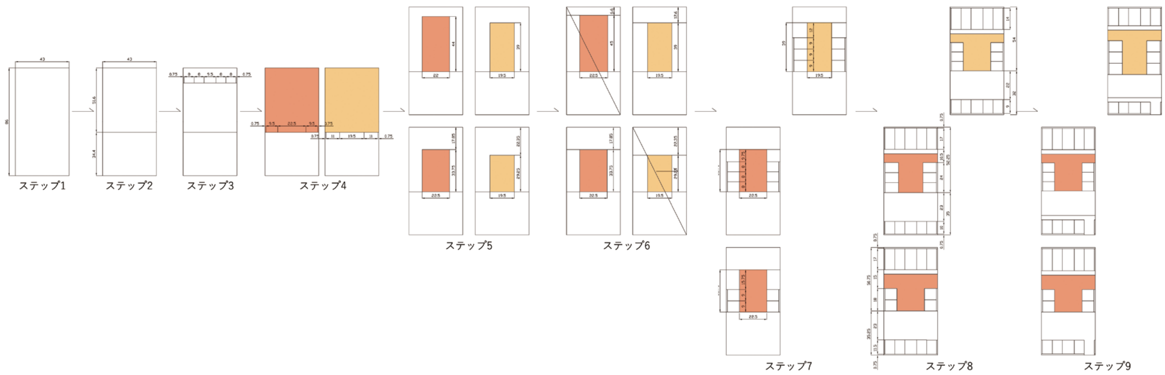


Figure10　The formation process of Siheyuan plane (when the width and length ratio of the building site is 1 to 2)

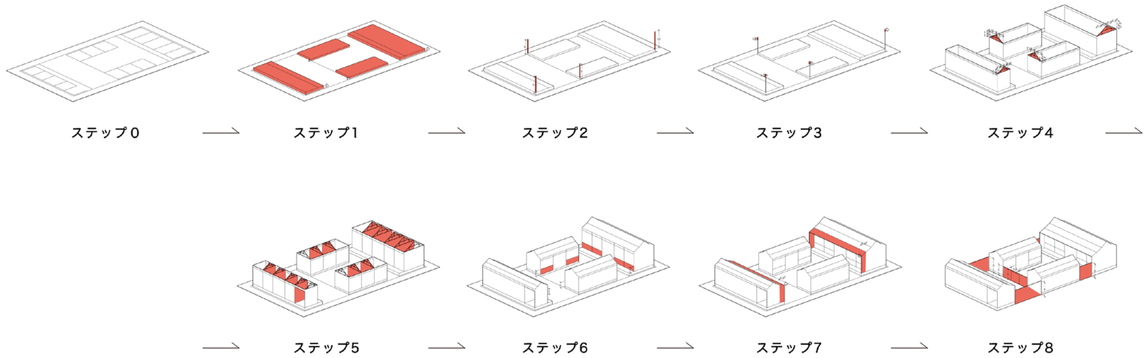
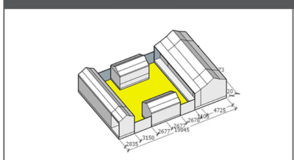
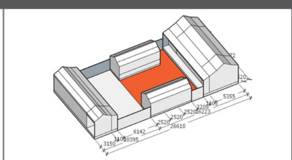
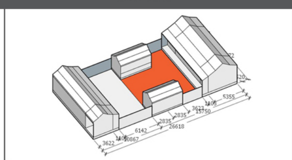
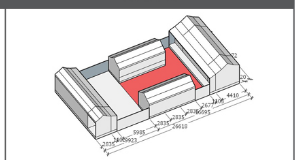


Figure11　The formation process of Siheyuan elevation model

3Dモデル	3Dモデル	3Dモデル	3Dモデル
			
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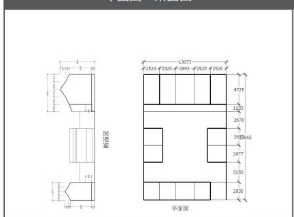
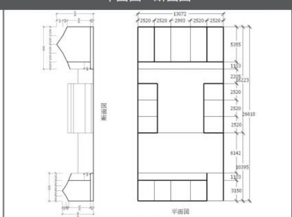
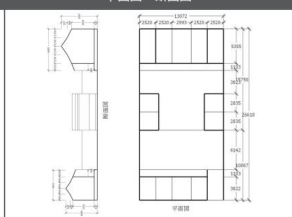
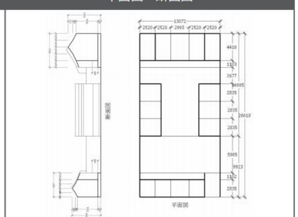
			
タイプ　庭数　庭の間口 / 奥行　廂房の室数	タイプ　庭数　庭の間口 / 奥行　廂房の室数	タイプ　庭数　庭の間口 / 奥行　廂房の室数	タイプ　庭数　庭の間口 / 奥行　廂房の室数

Table3　4 types of Siheyuan 3D models and their characteristics in winter, even when they are not sleeping. So far, there was such a problem in the simulation experiment of the indoor environment of Siheyuan, that was, the simulation experiments have been carried out without kang. In this research, it was considered that the function of kang in regulating indoor climate and temperature, especially in winter, cannot be ignored. So, to simulate and reproduce the real indoor thermal environment of Siheyuan in Qing Dynasty, the research should not only have the space model of Siheyuan, but should also consider the use of the heating system at that time. From the perspective of regional studies, this chapter firstly refers to the studies of dwellings in and around Beijing in the early 20th century, immediately after the Qing dynasty, in order to create a modelling of the kang. This is followed by interviews and observations on the pattern of life using kangs, and the modelling of energy input patterns into kangs.

3.2 Making Models of Kang

3.2.1 The location of the Kang

Japanese scholars Murata and Kurata have noted the location of kang when they investigated the Siheyuan (Figure 12). It can be seen that kang is usually placed in Cijian and Shaojian.

The kang in Cijian is usually near the courtyard.

The kang in Shaojian is near the outer wall.

3.2.2 Structure and Materials

ITO, also a Japanese scholar, collected the plan and sections of a kang in his book "The Residence of the North Branch". It provides valuable reference materials for understanding the

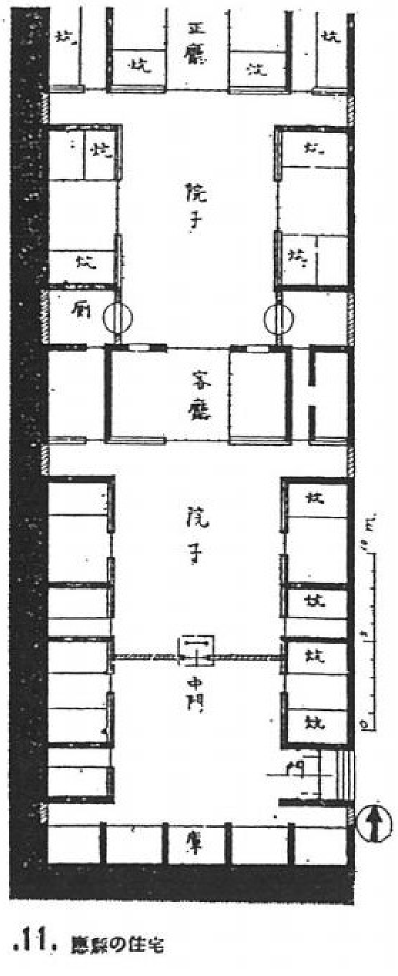


Figure12 A plan of the siheyuan with kang

Murata, J. (1938). Houses in northern China (北支の住宅 , Japanese edition). Houses, 226.

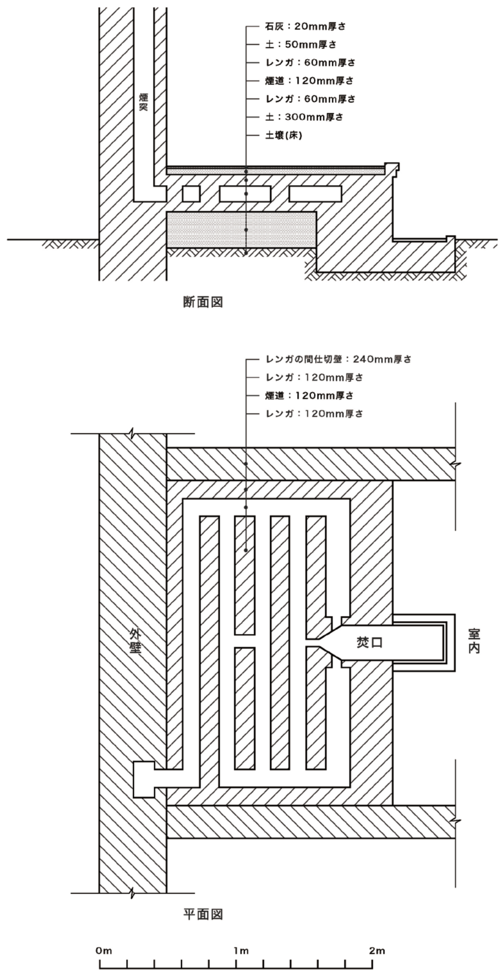


Figure13 A construction drawing of kang

Ito, T. (1943). Houses in northern China (北支蒙疆の住居 , Japanese edition), Japan: OUBUNDOU Publishers Inc. pp.53.

Figure16　Food preparation in a room with Kang

Figure14　Interview Scene, Yungang town, Datong city

Figure17　coal fire pit of Kang

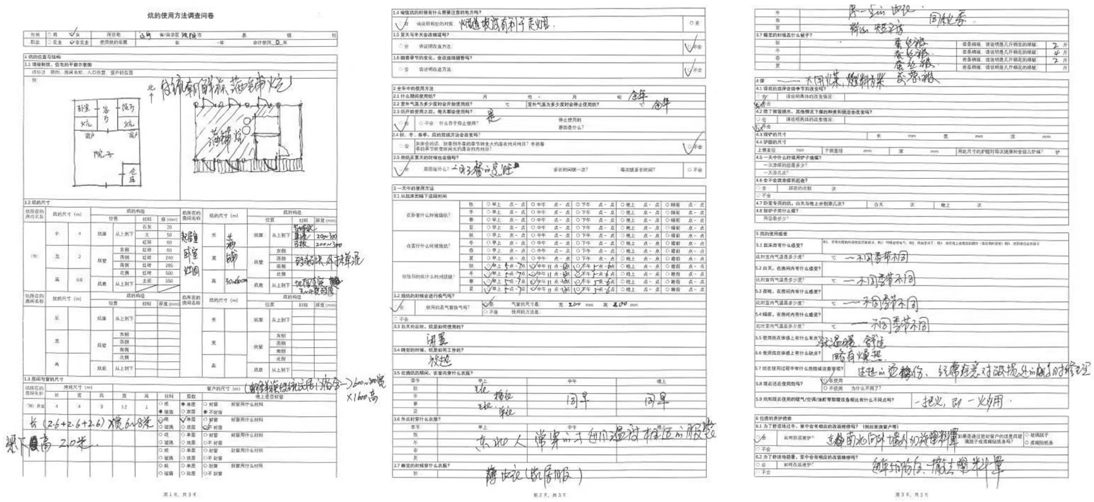


Figure15　A photo of a questionnaire

Figure18　The traditional suspended ceiling of siheyua

structure and size of kang. As can be seen from the figure 13, kang is mainly made of bricks. There is a flue opening, in which objects are placed to be burned. After burning, hot air will circulate in the flue in the kang, so as to heat up the kang, and the smoke will be discharged to the outdoor through the chimney.

3.3　Restoration of Usage Method

3.3.1　Fuel

Kangs are no longer used in Beijing today, but kangs continued to be used in some areas of the surrounding provinces until the second half of the 20th century, and are still used in rural areas today. So, we interviewed people in those areas (Figure 15). The locations of the survey were mainly Shenyang, northeast of Beijing, Datong, west of Beijing, and Inner Mongolia, north of Beijing.

3.3.2　Heating time

According to the questionnaire survey, the use of kang can be divided into cooking kang and non-cooking kang according to whether they participate in cooking. Meanwhile, in addition to kang, heating equipment may also use the stove.

Since there is no mention of stove in the questionnaire in Inner Mongolia, it seems that only kang is used as heating equipment. This is similar to Qing Dynasty Beijing, so in this research the burning time of Inner Mongolia has been used as a template to simulate the use of Beijing.

In Inner Mongolia, the kang for cooking is heated for one hour from 5 to 8 in winter, one hour from 11 to 12, and one hour from 17 to 18. The non-cooking kang in the living room (equivalent to the kang in Cijian of the main house) is heated for two to four hours between 16:00 and 20:00 in winter. In the bedroom, the non-cooking kang (equivalent to the kang in Shaojian of the main house) heats for two to four hours between 16:00 and 20:00 in winter.

In the Qing Dynasty, the kang used for cooking in Beijing Siheyuan was not usually installed in the main house, so only the heating of the kang used for non-cooking was considered in the simulation experiment of the indoor climate environment in the main house in winter. This is Pattern A.

In a case in Inner Mongolia, the bedroom will also be heated in the morning, and the bedroom will be used as a living room during the day. In other words, if there are people in the living room during the day, one can consider adding a heated kang to raise the indoor temperature. According to this idea, it can be inferred that Cijian of the Siheyuan in Beijing during the Qing Dynasty may also have heated kang in the morning and during the day. This is pattern B.

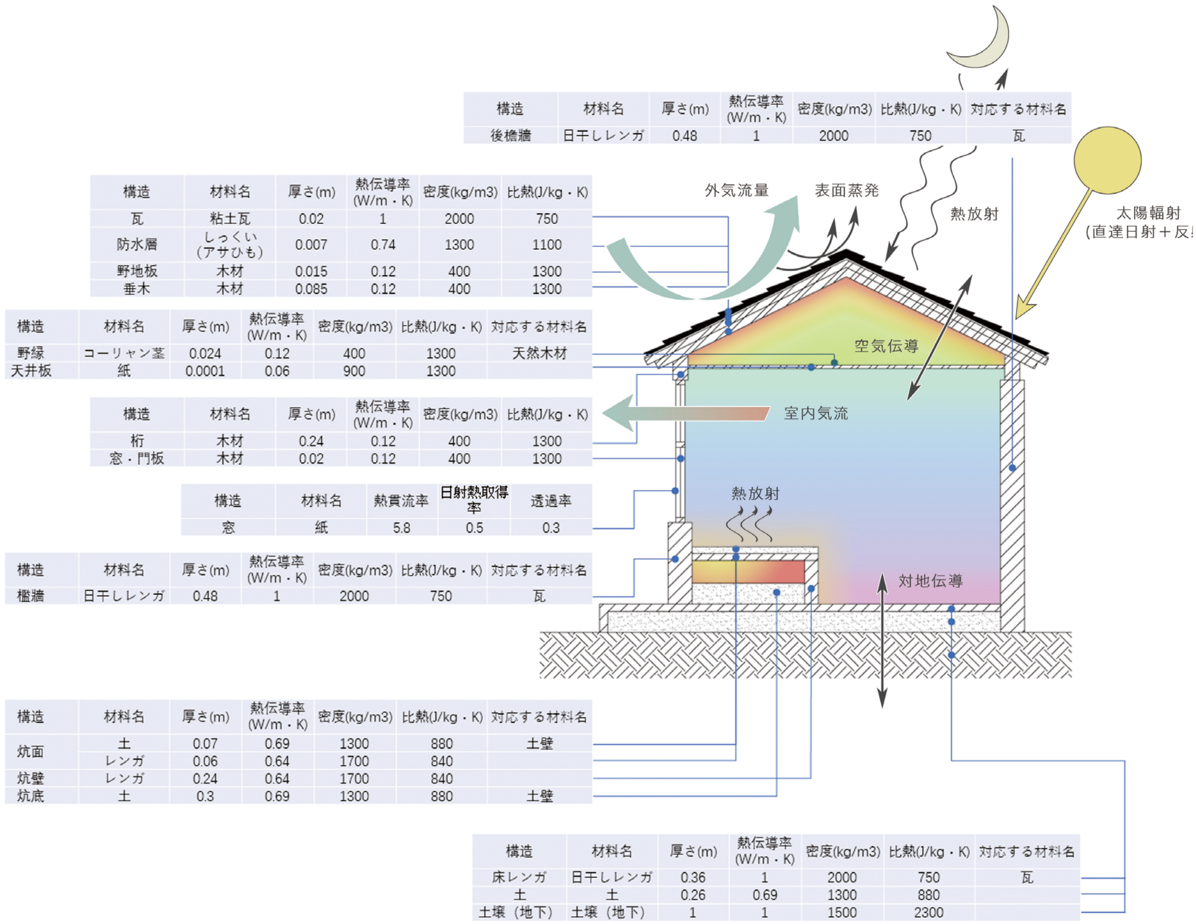
3.3.3　Calculation of heat

According to the questionnaires, heating the kang for non-cooking uses 1.5 to 2 kilograms of coal per hour. Since building a simulation requires input of energy per square meter, not weight, some conversions were required and 1.5 kilograms per hour was taken as the minimum.

First, kilograms per hour were converted into watts. By removing the floor area of the kang, the energy required per square meter to add the kang to Cijian and Shaojian was identified. Cijian needs 726.4 watts per square meter and Shaojian needs 414.1 watts per square meter.

Suspended ceiling

In addition, it was also found in the questionnaire survey that the room with kang has a suspended ceiling with stick paper on the wooden keel (Figure 18). This is thought to reduce the indoor air flow and create a layer of air insulation in the attic. Buildings in the Forbidden City of the Qing Dynasty had suspended ceilings, so in this research



構造	材料名	厚さ(m)	熱伝導率 (W/m・K)	密度(kg/m3)	比熱(J/kg・K)	対応する材料名
後檐牆	日干しレンガ	0.48	1	2000	750	瓦

構造	材料名	厚さ(m)	熱伝導率 (W/m・K)	密度(kg/m3)	比熱(J/kg・K)
瓦	粘土瓦	0.02	1	2000	750
防水層	しっくい (アサひも)	0.007	0.74	1300	1100
野地板	木材	0.015	0.12	400	1300
垂木	木材	0.085	0.12	400	1300

構造	材料名	厚さ(m)	熱伝導率 (W/m・K)	密度(kg/m3)	比熱(J/kg・K)	対応する材料名
野縁	コーリャン茎	0.024	0.12	400	1300	天然木材
天井板	紙	0.0001	0.06	900	1300	

構造	材料名	厚さ(m)	熱伝導率 (W/m・K)	密度(kg/m3)	比熱(J/kg・K)
桁	木材	0.24	0.12	400	1300
窓・門板	木材	0.02	0.12	400	1300

構造	材料名	熱貫流率	日射熱取得率	透過率
窓	紙	5.8	0.5	0.3

構造	材料名	厚さ(m)	熱伝導率 (W/m・K)	密度(kg/m3)	比熱(J/kg・K)	対応する材料名
檻牆	日干しレンガ	0.48	1	2000	750	瓦

構造	材料名	厚さ(m)	熱伝導率 (W/m・K)	密度(kg/m3)	比熱(J/kg・K)	対応する材料名
炕面	土	0.07	0.69	1300	880	土壁
	レンガ	0.06	0.64	1700	840	
炕壁	レンガ	0.24	0.64	1700	840	
炕底	土	0.3	0.69	1300	880	土壁

構造	材料名	厚さ(m)	熱伝導率 (W/m・K)	密度(kg/m3)	比熱(J/kg・K)	対応する材料名
床レンガ	日干しレンガ	0.36	1	2000	750	瓦
土	土	0.26	0.69	1300	880	
土壌（地下）	土壌（地下）	1	1	1500	2300	

Figure19 The space model of the building, the physical properties of various materials, the impact of the environment, work together to form indoor climate

it was assumed that the courtyard houses of the Qing Dynasty also used suspended ceilings to improve indoor comfort.

4. Constructing A Simulation Experiment System

By integrating the findings from the architectural history research in Chapter 2 and the regional research in Chapter 3, an environmental engineering simulation was performed to reproduce the microclimate, which means air condition, inside Siheyuan of Qing Dynasty in Beijing. By constructing a program with a computer, a system for simulation experiment was built with reference to a comprehensive space model of the building, the physical properties of various materials, the impact of the environment and climate on the building (Figure 19).

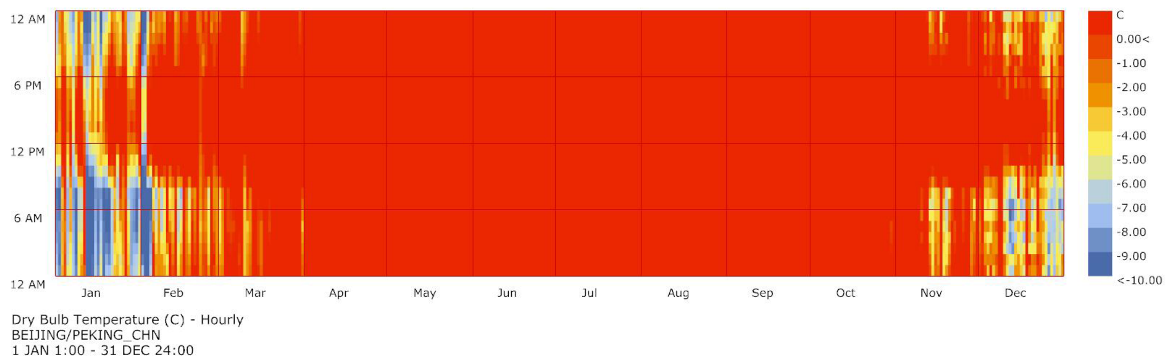


Figure20 Annual temperature in Beijing derived from EPW climate data

Through the "Rhino" and "Grasshopper" computer software, Siheyuan space model was produced. The indoor heat source kang was built through the "ladybug" plug-in and then construction and material data, climate data, ventilation and air leakage data were imported to it. By carrying on the simulation experiment calculations, the result visualization was finally calculated.

The visualization results are dated January 12. It can be seen from Figure 20, that the outdoor temperatures in January were the lowest of the year, and the 12th was one of the coldest days of the month. In addition, the temperature did not change significantly in the days before and after January 12, which was a period of stability.

On January 12, the lowest temperature was -12.5 degrees Celsius at 6 am. After that, the temperature gradually increased. At 4 pm, the temperature reached to the highest level of the whole day, -5 ℃ . Then the temperature drops gradually.

5. Interpretation of The Simulation Results

5.1 Pattern A

First, attention was given to the Pattern A. This result reflects the living condition of the main house of Beijing Siheyuan in Qing Dynasty. The main house has five rooms, and there are kang in Cijian and Shaojian. The heating time of kang is from 16:00 to 20:00 and has a suspended ceiling.

The results were exported every three hours, so each group consists of eight graphs, each representing an average of one hour. To make the calculation easier, the number of air changes inside the kang was set to 0.

Pattern A-1(Heated kang, with suspended ceiling)

Following are the first set of pictures (Figure 21). This set of graphs shows the average indoor temperature. In order to show the situation inside the kang at the same time, a position 0.5 meters above the ground was chosen.

In the picture from 7 to 8 o 'clock, the room temperature in the westernmost room was 4-6 ℃ , the lowest among the five rooms, while the room temperature in the middle was 14-16 ℃ , the highest among the five rooms. At this time, the

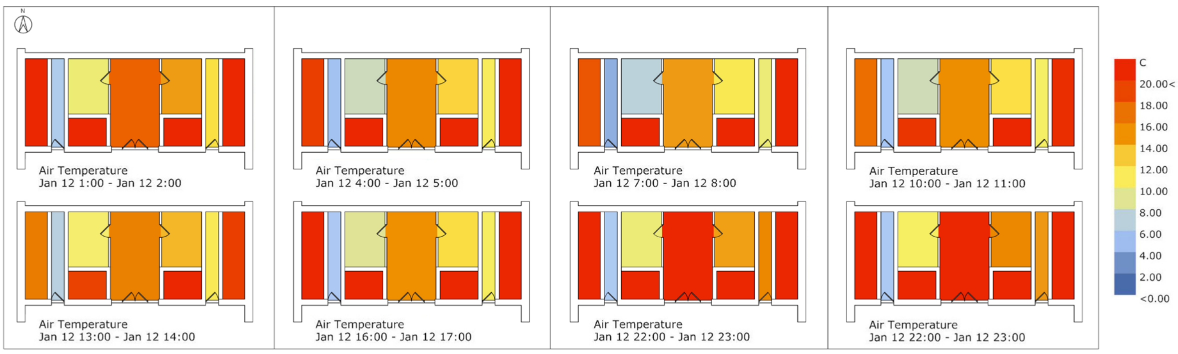


Figure21 Air temperature (Heated kang, with suspended ceiling)

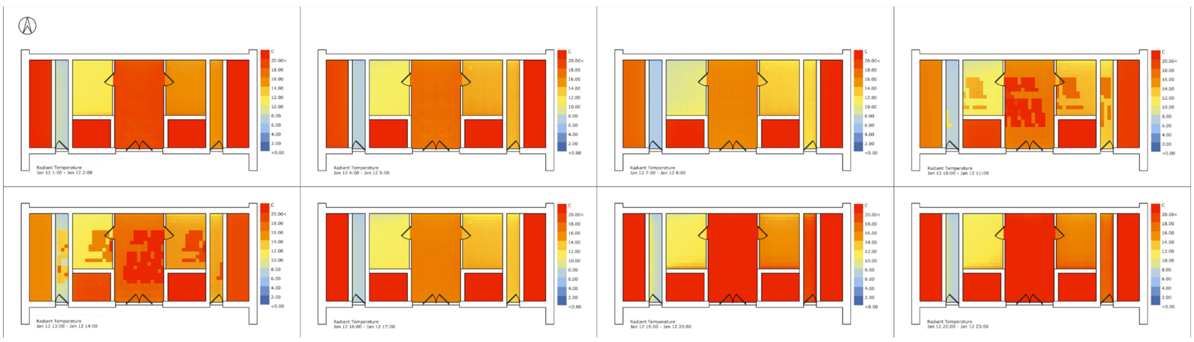


Figure22 Radiant temperature (Heated kang, with suspended ceiling)

temperature is the lowest in a day, the outdoor temperature is -12.5℃ , the temperature difference between indoor and outdoor reaches the lowest 16.5-18.5 ℃ and the highest 26.5~28.5℃ , indicating that the system is effective in improving the environmental temperature.

The room temperature in the middle is higher than that on the two sides, presumably because of the heat transfer generated by the kang on both sides. The indoor temperature of the two rooms on the east side is higher than that of the two rooms on the west side. It is speculated that there is northwest wind in Beijing in winter, and the cold wind makes the temperature of the room on the west side lower.

The second group shows radiation temperature (Figure 22). Even in the room on the west side, where the radiation temperature is the lowest, the temperature stays at 6 to 10 degrees Celsius throughout the night, indicating that the kang, with its high heat storage capacity, has improved indoor comfort. The radiant temperature of the two rooms on the east side is higher than that of the two rooms on the west side. The reason should be the same as room temperature, which is caused by the northwest wind in winter.

The third group shows the indoor temperature and radiation temperature of the westernmost room and the western Shaojian (Figure 23 and 24). It can be seen from the figure that the heat insulation effect of the ceiling is obvious.

In addition, the radiation temperature within 0.2m from the kang surface is 2-4 ℃ higher than other places. It can be seen that people feel more comfortable when sitting on the surface of the kang.

The fourth group shows the surface temperature of the kang (Figure 25). As can be seen from the figure, the temperature reaches its maximum value from 22:00 to 23:00, and then gradually decreases, but it is still higher than room temperature (3-5 ℃ higher than room temperature), which further verifies the conclusion that people feel more comfortable when sitting and lying on the surface of kang.

Pattern A-2(No heated kang, no suspended ceiling)

Then the indoor temperature and the indoor radiation temperature were simulated under the condition of "no Suspended ceiling, kang is not heated" (Figure 26 and 27). This is the case with the Siheyuan now protected as a historical relic.

As can be seen from the picture, the indoor temperature is only 6 degrees Celsius when it reaches the highest point of the whole day. Most of the time the temperature in the room is around zero degrees Celsius. If other heating measures are not taken, the comfort level of people cannot be satisfied.

Pattern A-3(Heated kang, no suspended ceiling)

Next, a simulation experiment was conducted under the condition of " heated kang and no suspended ceiling " (Figure 28 and 29). As can be seen from the picture, the temperature of each room in this condition is 4~8℃ lower than that of "with suspended ceiling and heated kang". Thus, the suspended ceiling plays an important role in raising the indoor temperature.

Pattern A-4(No heated kang, with suspended ceiling)

After that, a simulation experiment of "with a suspended ceiling, kang is not heated" (30 and 31) was conducted. It can be seen that although the suspended ceiling can raise the indoor temperature a little, the interior is still not comfortable because there is no heated kang.

Next, a model of the main house with only three rooms was made and a simulation experiment was conducted. When investigating Siheyuan dimensional system, it was found that the main house of Siheyuan consists of 5 rooms. It was questioned that, besides the large population of each household in Qing Dynasty, whether it is also related to the improvement of indoor climate conditions? With this question in mind, a simulation experiment was carried out on the main house

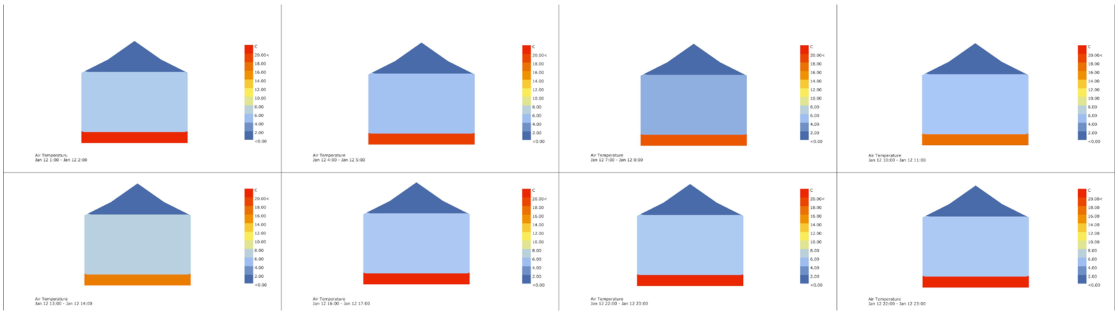


Figure23　Air temperature of western Shaojian (Heated kang, with suspended ceiling)

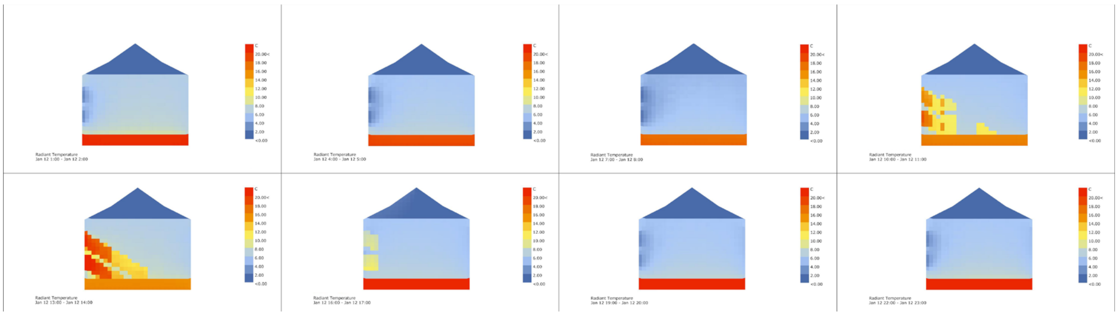


Figure24　Radiant temperature of western Shaojian (Heated kang, with suspended ceiling)

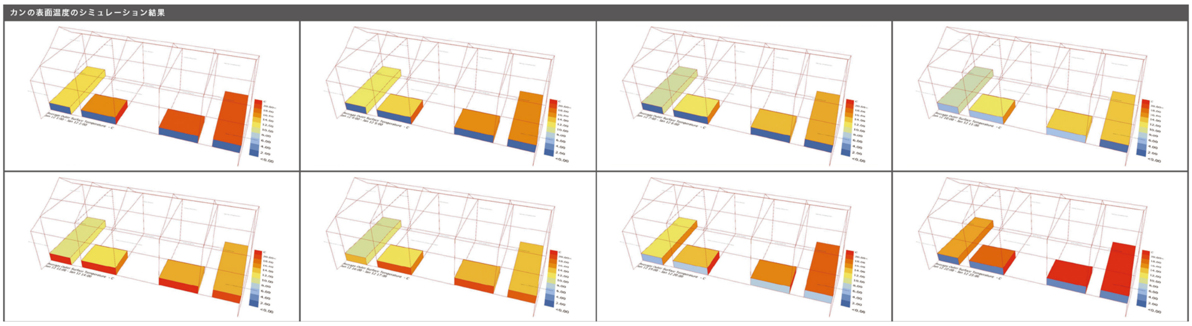


Figure25　Surface temperature of Kangs (Heated kang, with suspended ceiling)

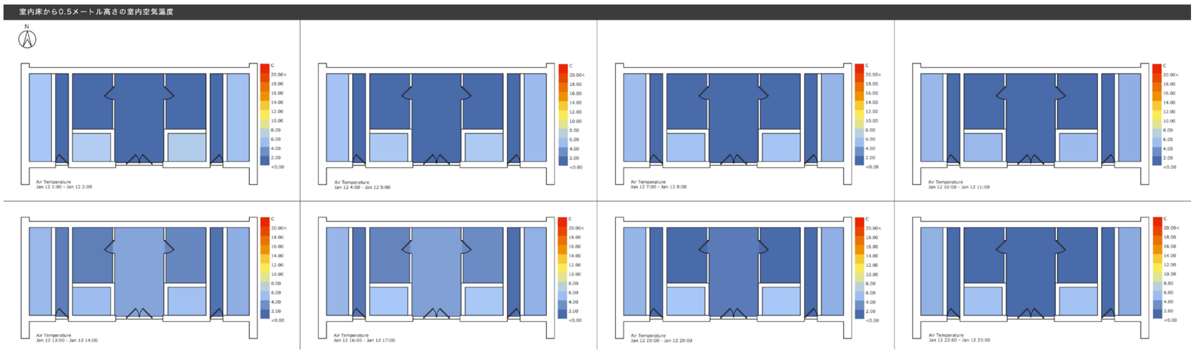


Figure26　Air temperature (No heated kang, no suspended ceiling)

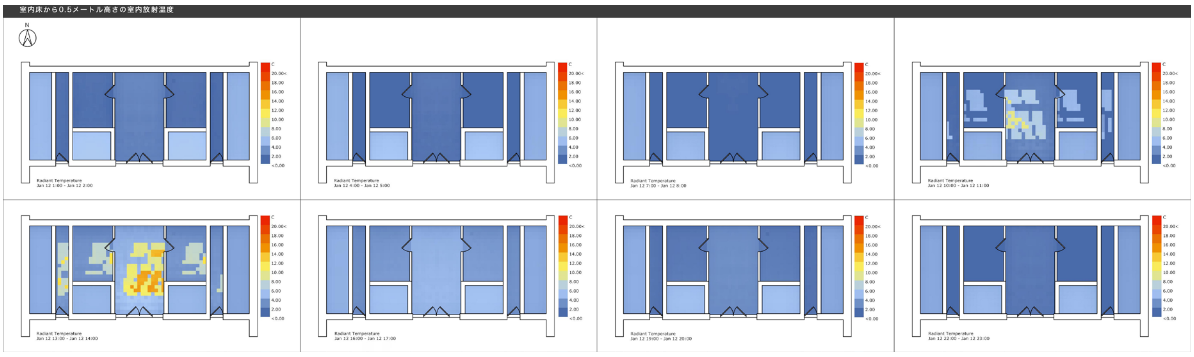


Figure27　Radiant temperature (No heated kang, no suspended ceiling)

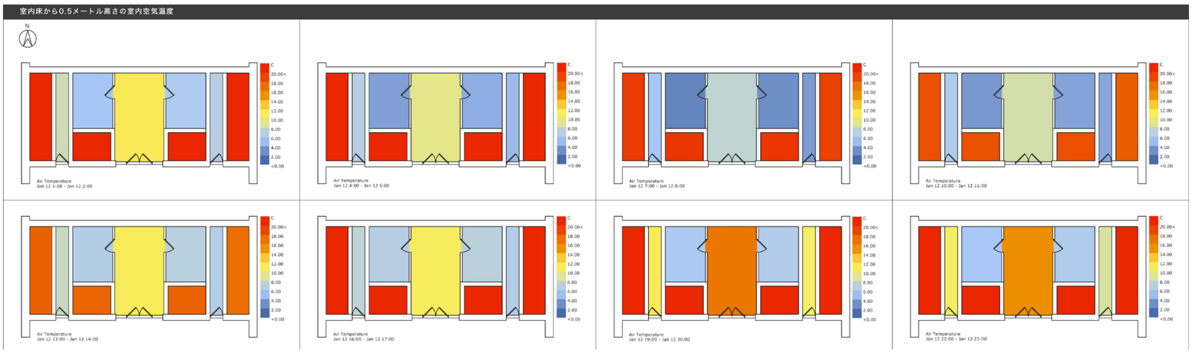


Figure28　Air temperature (Heated kang, no suspended ceiling)

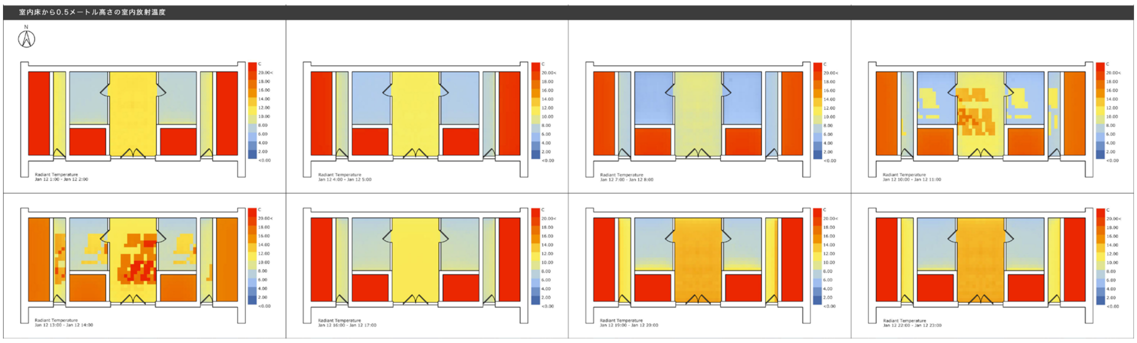


Figure29　Radiant temperature (Heated kang, no suspended ceiling)

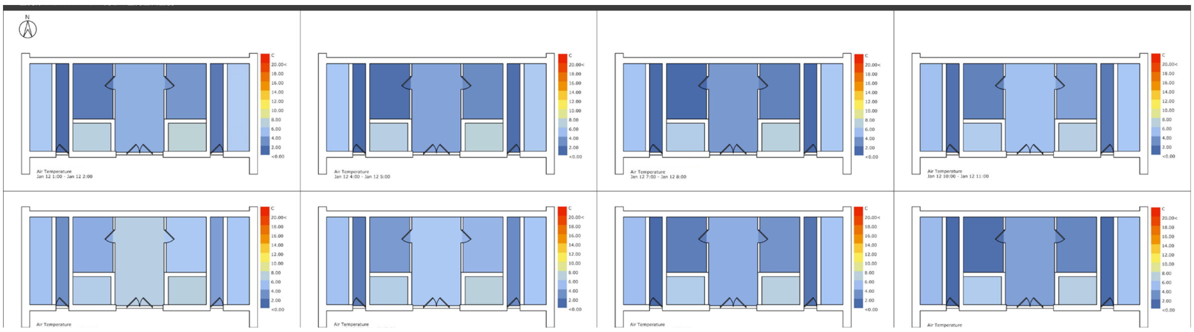


Figure30　Air temperature (No heated kang, with suspended ceiling)

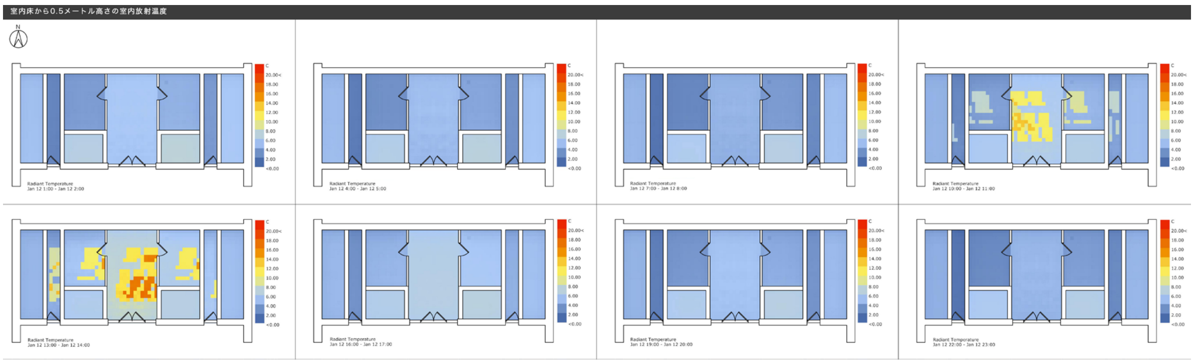


Figure31　Radiant temperature (No heated kang, with suspended ceiling)

with only three rooms.

As can be seen from the figure 32 and 33, the temperature of the rooms on both sides at this time is 2-4 ℃ lower than that of the rooms on both sides of the main house of the five rooms. The two outermost rooms of the five rooms can be used as an insulation space to raise the room temperature and make it more conducive to living.

To sum up, following points can be seen from the simulation experiment:

1. The northwest wind in winter will lower the indoor temperature of the west room.

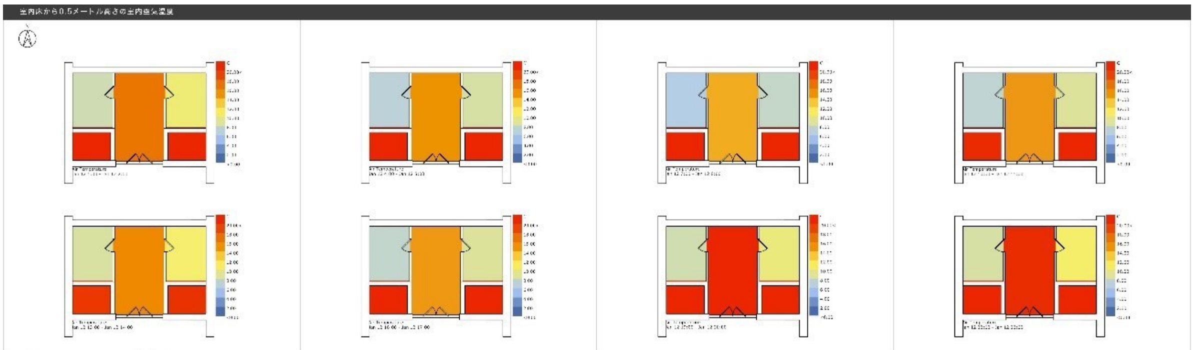


Figure32　Air temperature, only has three rooms (Heated kang, with suspended ceiling)

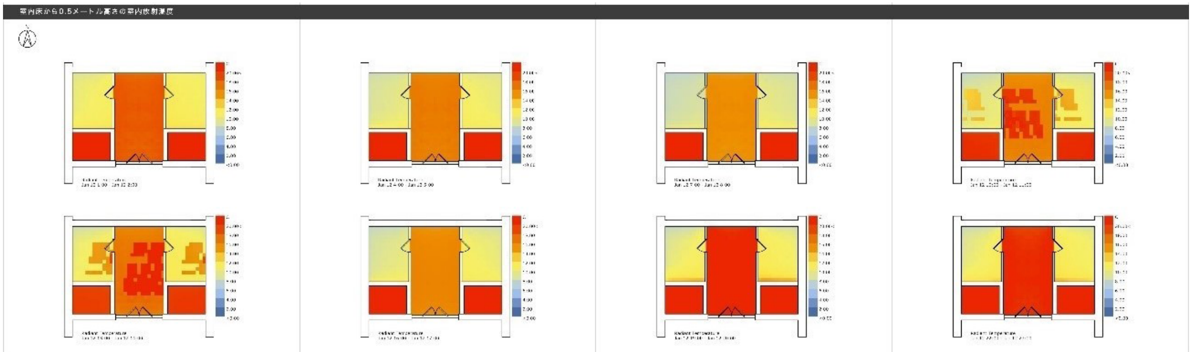


Figure33　Radiant temperature, only has three rooms (Heated kang, with suspended ceiling)

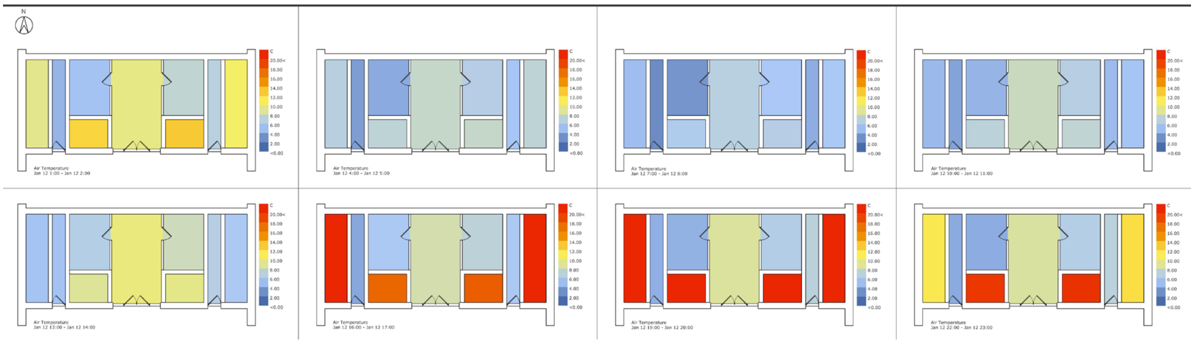


Figure34　Air temperature, the ventilation is considered (Heated kang, with suspended ceiling)

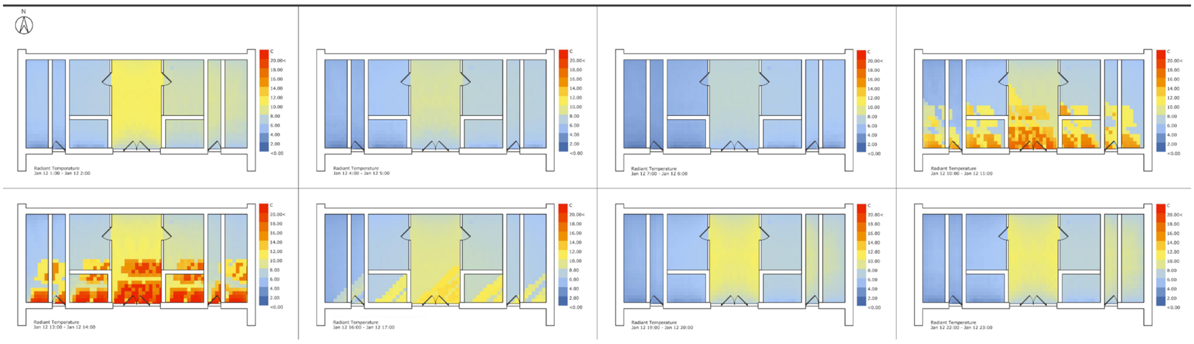


Figure35　Radiant temperature, the ventilation is considered (Heated kang, with suspended ceiling)

2. A main room with five rooms is warmer than a main room with three.
3. The ceiling can be used as an insulation layer, reducing the volume of indoor air and improving the temperature of the room.
4. The heat conduction between kang and human is the key to improving human comfort.

5.2　Change the air exchange rate and increase the heating time of kang

The results of the simulation experiments just

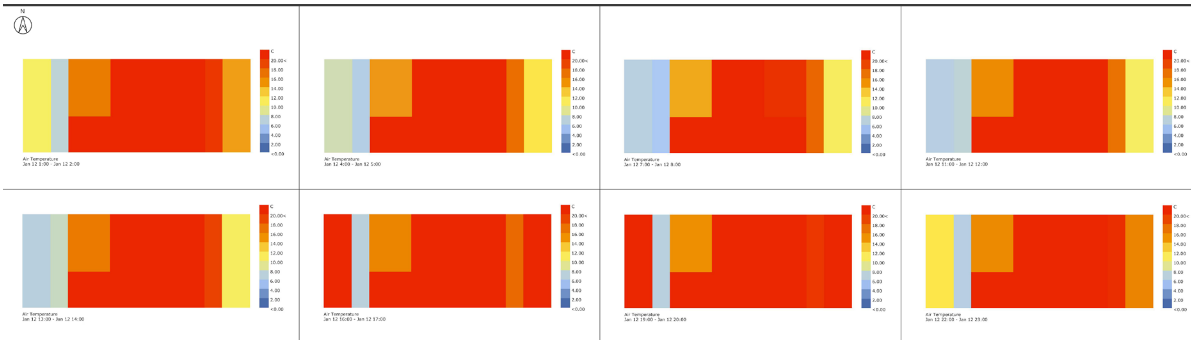


Figure36　Air temperature, the ventilation is considered (Heated kang, with suspended ceiling), Pattern B

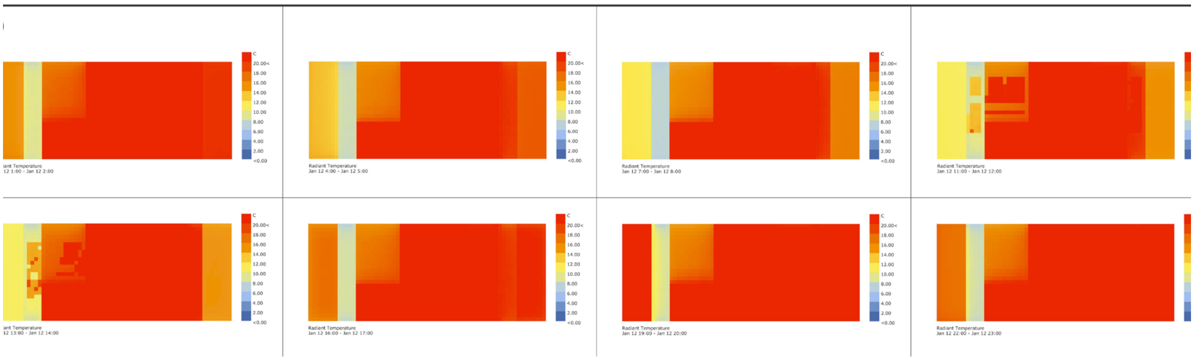


Figure37　Radiant temperature, the ventilation is considered (Heated kang, with suspended ceiling), Pattern B

shown are all carried out under the condition of zero air changes, but this is not consistent with the fact that the heat inside the kang is actually discharged to the outside through the chimney. Therefore, on the basis of Pattern A, a new simulation experiment was carried out with the addition of air exchange.

As shown in the figure 34 and 35, the indoor temperature is 2~8 ℃ between 7 and 8 o 'clock when the temperature is the lowest. The temperature is relatively low and does not meet the comfort needs of the human body.

After that, the simulation experiment of Pattern B, based on the consideration of the ventilation, was carried out. In Cijian two hours of burning time between 5am and 6am and 11am and 12am were added.

As shown in the figure 36 and 37, when the temperature is the lowest from 7 to 8 o 'clock, the indoor temperature of the three rooms in the middle is 14-20 ℃ , which makes people feel comfortable. After getting up, people will do activities in the three rooms in the middle.

Therefore, this research indicates that the heating time of kang in the main room of Siheyuan in Qing Dynasty should be morning, noon and evening in winter.

6. Conclusion

This cross-disciplinary study was carried out by combining findings from three different academic areas: Chinese Architectural History, Chinese Area Studies, and Environmental Engineering. By integrating the knowledge gained from the three different academic areas, through simulation, the indoor air condition of ZhengFang of the Siheyuan of Qing Dinasty, Beijing during the winter was clarified and its comfort was evaluated. In the particular research area, the dimensional system of Siheyuan of Qing Dinasty, Beijing was clarified, and records on the lifestyle using “kang” were created.

The results of the simulation revealed the following four points.

1. Seasonal winds from the northwest had affected the indoor air conditions, and western rooms had had lower air and radiation temperatures than the eastern ones.
2. In the plan which consists of five spans, which was common in ZhengFang, the spans of both ends had acted as heat insulating layer to the outside and the air temperature and radiation temperature in the central

three spans had been kept higher than that of the plan consists of only three spans.

3. The paper-covered suspended ceiling, which had reduced the indoor air volume and which at the same time had created an attic insulation layer, is an effective mechanism for keeping the indoor air temperature and radiation temperature high.
4. If charcoal for Kang had been burned in an amount of 1.5 kg per hour, it had been possible to keep the air temperature of most of the rooms above 20 degrees Celsius by burning it three times in the spans beside the central span: 1 hour in the morning, 1 hour in the afternoon and 2 hours in the evening and 4 hours in the evening in the end-spans.

From the above findings following suggestions for the conservation of Siheyuan of Beijin as cultural heritage buildings and suggestions for the architectural designing in contemporary Beijin can be derived.

Currently, the conservation of the Siheyuan of Beijin as a cultural heritage building is solely focused on its physical form. Reconstructing the Kang and their burning methods, which are forgotten today, enables comprehensive conservation, including the thermal environment of the time and the unique experiences it brings. The heat conduction between Kang floor heating system and people is considered to be the key to the comfortable experience unique to Siheyuan of Qing Dinasty, Beijing. The suggestions for architectural design in contemporary Beijing are as follows. It is desirable to place a main living room on the east side where the air temperature and the radiation temperature are higher than the west side. In addition, the establishment of an air insulating layer between the main living room and the outdoor can be an effective mechanism to keep the air temperature and the radiation temperature of the main living room high.

The construction of models and the implementation of simulations on computers are effective media for integrating findings in different research areas. The model of the dwelling which was created by extracting several elements and their systems from the real field and the results of their simulations can be described as the virtual field which was reconstructed from the real field at the scale of a dwelling. By manipulating the parameters of the model, the possible appearances of the field which are different from the present can be explored, such as the past or the future. The characteristics of the fields can be analyzed from the simulation results. The findings obtained from this model and simulation are different from the findings from individual research areas, and they bring a new perspective to us. The new perspective has the potential to create new research areas that will renew our perception of the world.

Acknowledgments

The author would like to thank Prof. Yamada Kyota (University of Tsukuba) for his thorough guidance given in writing this paper and Assoc Prof. BAO Muping (Yamato University) and UNO Tomoko (Mukogawa Women's University) for their guidance on the survey methodology and Mr. Yuichi Yasuda and Ms. Yoshie Matsumoto (Quattro Co., Ltd.) for their suggestions on the development of the simulation methodology.

he author is also grateful to Mr. ZHEN Fuchun and Ms. WANG Xiang, and the survey respondents who supported the interview survey in China.

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